

# First-Flight Adult European Corn Borer (*Lepidoptera*: Crambidae) Distribution in Roadside Vegetation Relative to Cropping Patterns and Corn Phenology

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**ABSTRACT** The European corn borer, *Ostrinia nubilalis* (Hübner), is a serious pest of commercial maize throughout the U.S. Corn Belt. Adults in the central and eastern Corn Belt aggregate in grassy areas around and within the cornfield where they spend the daylight hours resting and where mating activity occurs at night. Mated females leave the aggregation sites at night to oviposit in cornfields, thus using the grass as a staging area. Flush samples were taken in borrow ditches in central Iowa during the first (spring) flight of moths in 2003 and 2004 to determine if cropping patterns and crop phenology influence moth distribution across the landscape. Significantly more moths were present in ditches with an adjacent cornfield on at least one side of the road than in those with no corn on either side. In contrast, effects of corn stubble from the previous year's crop, tillage, and corn phenology were weak or not detectable. Evidence suggests that some moths emerging from corn stubble may aggregate in adjacent grass but that they redistribute themselves in the landscape within a short time. Thus, the presence or absence of adjacent corn was the overwhelming factor affecting spatial distribution of first-flight European corn borer moths among grassy roadside ditches.

**KEY WORDS** *Ostrinia nubilalis*, European corn borer, spatial distribution, landscape, dispersal

THE EUROPEAN CORN BORER, *Ostrinia nubilalis* (Hübner), is a chronic and serious pest of commercial maize (corn) throughout the U.S. Corn Belt (Mason et al. 1996, Ostlie et al. 1997). In central Iowa and much of the Corn Belt, this insect is bivoltine with two distinct periods of moth abundance, commonly called flights, lasting 4–6 wk each: one in the spring and one in the summer. Corn borers overwinter as full-grown larvae within corn stalks, pupating and emerging as adults in the spring. The resulting first flight of moths occurs from mid-May through mid-June, with females ovipositing on whorl-stage corn, leading to first-generation infestations. Later instars of first generation larvae bore into the stalk and eventually pupate. The ensuing second flight of moths usually lasts from mid-July through August, and their offspring constitute the second generation, which overwinter as diapausing fifth (last) instars (Mason et al. 1996).

European corn borer moth behavior is complex and not well-understood. It was recognized long ago that the moths are often found resting in grassy areas near or within cornfields during the daylight hours (Cafrey and Worthley 1927). Showers and colleagues focused on these sites in a series of studies and showed

that they also are used for mating activity (Showers et al. 1974, 1976, DeRozari et al. 1977, Sappington and Showers 1983b), although irrigated corn may be more attractive than grass for resting and mating in more arid regions (Hunt et al. 2001). Mason et al. (1996) mentioned that soybean, potato, and cotton also can serve as resting and mating sites. Much is known about the characteristics of the European corn borer adult aggregation sites themselves, including species composition, grass height, vegetation density, canopy closure, and vegetative structure (Showers et al. 1976, 2001, Hellmich et al. 1998, Pleasants and Bitzer 1999, Anderson et al. 2003). Thus, the factors that make an individual site suitable for moth aggregation are relatively well described, but the need to search among grassy areas for moth concentrations (Sappington and Showers 1983a, Derrick and Showers 1990, 1991) suggests that not all suitable sites harbor moth aggregations. What influences the choice of a particular grassy site for aggregation, among many potentially suitable sites, is a landscape-level question that has not been systematically addressed. Understanding this organism's population ecology will require understanding processes that are happening at larger spatial scales (Kennedy and Margolies 1985, Tschamntke and Brandl 2004).

The goal of this study was to determine whether distribution of European corn borer moths among grassy habitats during the first flight is random across

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agricultural landscapes roughly 20 km in diameter. Very little is known about the dispersal behavior of this moth, but there is evidence from lake-crossing, range-expansion, and mark-recapture data that dispersal can occur in the range of 25–80 km (Caffrey and Worthley 1927, Chiang 1972, Showers 1979, Showers et al. 1995, 2001). Thus, it is likely that the moths sampled within a year in this study were members of the same population, defined as a group of potentially interacting/interbreeding individuals coexisting in time and space (Hedrick 1983, Hanski and Simberloff 1997). More specifically, my goal was to examine what obvious potential landscape features may influence the spatial distribution of aggregation sites, including proximity to corn, proximity to the natal field, tillage, and corn phenology.

### Materials and Methods

Experiments were conducted in Hamilton and Hardin Counties, IA, near Randall and Radcliffe, from 12 to 18 June 2003, and in Marshall County, near Melbourne, from 26 May to 17 June 2004. Sites for flush samples were selected based on having at least 100 m of grass in one (2003) or both (2004) borrow ditches flanking gravel roads, which appeared suitable as European corn borer moth aggregation sites. Ditches with sparse grass or containing substantial proportions of unsuitable plants such as Canadian thistle, horsetail, or nutsedge were avoided. A measuring tape was used to delimit a distance of 100 m in each ditch to be sampled. The grass canopy was disturbed the length of the 100-m sampling area with a 1.5-m plastic garden stake, and moths were counted as they were flushed from the grass as described by Sappington and Showers (1983a). Samples were taken only when wind speeds were  $\leq 15$  km/h and temperatures  $\geq 16^\circ\text{C}$ , because moths are less likely to take flight in windier or cooler conditions (Sappington and Showers 1983a).

The crops on both sides of the road were recorded, as were the previous year's crops, as determined by residue on the soil surface. Tillage was classified as conventional or minimum, the latter including no-till fields. Most crops were either corn or soybean, but occasionally were alfalfa, wheat, or pasture. In cornfields, 20 contiguous plants in one row were selected arbitrarily, but away from the field edge, and the number of leaves were counted (2003–2004), and extended leaf heights were measured to the nearest centimeter (2004).

Sample sites were classified as having corn on zero, one, or two sides of the road. On each day, an attempt was made to sample an equal number of each class of site. This goal was not always achieved, because of logistical constraints or increasing wind speeds that shut down sampling prematurely. Each sample site was classified in the same way based on the previous year's crops, but no attempt was made to balance daily sampling by site class. In 2003, a total of 35 sites were sampled one time each over 4 d near the peak of moth population levels. In 2004, 47 sites were each sampled twice, once early in the flight (26 May to 6 June), and

again later in the flight (9–17 June). Sites were always located at least 400 m distant from one another.

### Statistical Analyses

All analyses were performed using Statistix7 software (Analytical Software 2000). Numbers of flushed moths were not normally distributed, so nonparametric comparisons were used.

**Cropping Pattern.** In cases where corn was present on one side of the road only, the Wilcoxon matched-pairs signed-ranks test (Daniel 1990) was used to determine if the grass in the ditch nearest that cornfield harbored more moths than that on the other side of the road ( $\alpha = 0.05$ ). As will be reported in the Results section, there were no significant differences within sites associated with proximity to a single flanking cornfield, so all further analyses of 2004 data were conducted on summed moth numbers from both ditches.

One of the hypotheses to be tested was that European corn borer moth spatial distribution across the landscape is affected by the crops flanking potential aggregation sites. Given that the adult population changed over time during the  $\sim 4$ -wk flight period, it was necessary to restrict sample comparisons to those dates where the overall population levels were statistically similar. Consequently, the mean ranks for the number of moths flushed per site across all sites per date were compared with a Kruskal-Wallis one-way analysis of variance (ANOVA) (Daniel 1990) to identify subsets of dates with homogeneous distributions. Because it was of interest to identify sample dates with significantly similar, rather than significantly different, populations, the rejection level was  $\alpha = 0.20$ . This level reduces the chance of designating populations as being similar to one another when they are not. For dates with similar global populations of European corn borer moths, the Kruskal-Wallis one-way ANOVA was used to compare whether the number of moths flushed at a site differed depending on whether it was flanked currently, or in the previous year, by zero, one, or two cornfields. A similar test was conducted to compare moths flushed from a site with at least one adjacent field of minimum-till corn stubble versus sites with only conventional-till corn stubble on at least one side. The previous year's cropping pattern could affect moth distribution in the first flight, because the moths emerge in the spring from corn stubble after overwintering as diapausing larvae. Furthermore, mortality of overwintering larvae is less in minimum tillage corn than in conventionally tilled fields (Umezor et al. 1985), leading to the hypothesis that moths would be more abundant in ditches adjacent to minimum-till corn stubble than to tilled corn stubble.

A second analytical strategy was used to test the hypothesis that cropping pattern affects European corn borer adult distribution in potential aggregation sites across the landscape. Daily means were calculated for each site class, i.e., corn on zero, one, or two sides of the road. The Wilcoxon matched-pairs signed-

ranks test was conducted on the differences in daily means for each pairwise comparison. This approach benefits from including all sample dates, because it is based on paired comparisons within dates. The trade-off is a reduction in degrees of freedom because samples within dates are pooled. Tests were conducted for both the current and previous year's cropping patterns. A similar procedure was used to test for differences caused by tillage of corn stubble.

Changes in spatial distribution among the site classes over time was examined by linear regression. The ratio of moths from sites with no corn to moths from sites with at least one flanking cornfield for each sampling date was regressed on Julian date. This was conducted for both the current cropping pattern and that of the previous year. I hypothesized that the ratio would decrease over time as emergence from corn stubble decreased and moths progressively discovered and distributed themselves near preferred oviposition habitat, i.e., cornfields.

**Corn Phenology.** I hypothesized that European corn borer moths would be more abundant in ditches adjacent to fields with corn at more phenologically advanced stages, as indexed by the number of leaves or extended leaf height, than those at less advanced stages. Because corn phenology advances over time, it was necessary to restrict analyses to dates with statistically similar ( $\alpha = 0.20$ ) leaf counts or plant heights, as determined by a Kruskal-Wallis one-way ANOVA to identify subsets of dates with homogeneous distributions. As described above, it also was necessary to restrict analyses to dates with similar global moth populations that were changing over time. For each year, within the largest time window of similar crop phenology and global moth populations, the number of moths flushed from the grass was regressed on the average number of leaves or average extended leaf height in the adjacent cornfield. If there were two cornfields at a site, only measurements from the phenologically most advanced field were used. Suspected outliers after inspection of results were tested with a *t*-statistic according to Cook (1977) as implemented by Statistix7 software (Analytical Software 2000). *P* values were corrected using Bonferroni's inequality (Weisberg 1985).

## Results

### Cropping Pattern

**Current Year's Crop.** In 2004, moths were sampled on both sides of the road at each site. There were no significant differences in Wilcoxon matched-pairs signed-ranks comparisons between moths in north ( $16.7 \pm 2.47$ ) versus south ( $15.4 \pm 4.48$ ) ditches ( $n = 52$ ;  $P = 0.15$ ) or between moths in east ( $19.0 \pm 3.98$ ) versus west ( $9.7 \pm 2.09$ ) ditches ( $n = 42$ ;  $P = 0.07$ ). In cases where only one side of the road had corn, there were no more moths in the ditch on that side ( $15.7 \pm 3.47$ ) than in the ditch furthest away from the corn ( $17.2 \pm 3.33$ ;  $n = 30$ ;  $P = 0.70$ ). Therefore, I pooled moth counts from both ditches for each site in all subsequent comparisons.

**Table 1.** Mean  $\pm$  SE no. of European corn borer moths flushed from 100 m of grass per site per date and mean  $\pm$  SE no. of leaves per 20 corn plants per site per date, first flight 2003

Date	Flush samples		Corn phenology	
	No. sites	Moths/site	No. sites	Leaves/plant
June 12	7	44.4 $\pm$ 29.26a	4	7.3 $\pm$ 0.52a
June 16	6	39.3 $\pm$ 17.96a	5	8.9 $\pm$ 0.36a
June 17	18	24.7 $\pm$ 5.90a	14	7.8 $\pm$ 0.41a
June 18	4	22.0 $\pm$ 7.43a	3	8.8 $\pm$ 1.37a

When two cornfields were present at a site (i.e., corn on both sides of the road), only the one with the highest mean no. of leaves was used in comparisons between dates.

Means followed by the same letter are statistically similar ( $P > 0.20$ ), Kruskal-Wallis test.

The mean number of moths flushed across all sites was significantly similar for all four sample dates in 2003 (Table 1) and for most sample dates in 2004 (Table 2). However, in 2004, all pairwise comparisons that showed differences (at  $\alpha = 0.20$ ) involved the last three sample dates (Table 2) when moth populations were clearly in decline near the end of the flight. Therefore, 15–17 June were excluded from the Kruskal-Wallis tests comparing cropping patterns.

In both years, the number of moths in the grass was significantly greater in ditches where two cornfields were present than in ditches where corn was not present on either side of the road (Table 3). In 2004, there were significantly more moths in ditches with a single cornfield present than where no corn was present (Table 3). Wilcoxon matched-pairs signed-ranks comparisons of moths flushed per site class (zero, one, or two sides with corn) within all dates for 2003 and 2004 combined indicated that sites with corn present on at least one side harbored more moths in the adjacent grass than sites with no corn (Table 4). Although there was a trend for the number of moths in sites with corn on one side to be less than for sites with corn on both sides, the difference was not significant (Tables 3 and 4). The proportion of moths in sites without corn declined over time, as indicated by the regression of the ratio of moths in no-corn sites to moths in sites with corn on sampling date (Fig. 1A).

**Previous Year's Crop.** In contrast, European corn borer moth distribution on dates with similar moth populations (26 May to 14 June 2004; Table 2) was not affected dramatically by the cropping patterns of the previous year, as determined by the crop debris remaining in fields (Table 3). However, the reader is cautioned that interpretation is complicated by the common practice of corn-soybean crop rotation in central Iowa, making the previous year's crop and present year's crop not entirely independent variables in this data set. There were significantly fewer moths in ditches where there was no corn the previous year than in ditches where there was a single cornfield the previous year, according to the Wilcoxon matched-pairs signed-ranks comparisons over all dates (Table 4). The trend was in the opposite direction for zero versus two previous cornfields, and the comparison between zero cornfields versus sites with

Table 2. Mean no. of European corn borer moths flushed from 200 m of grass per site per date and pairwise comparisons by date, first flight 2004

Date	No. sites	Moths/site	Date									
			May 26	May 27	May 28	June 3	June 4	June 9	June 10	June 14	June 15	June 16
May 26	5	50.8 ± 0.37										
May 27	12	29.7 ± 5.94										
May 28	9	28.9 ± 4.52										
Jun 3	9	47.4 ± 3.80										
Jun 4	12	31.0 ± 8.20										
Jun 9	4	119.0 ± 8.39										
Jun 10	6	48.7 ± 6.43										
Jun 14	11	19.8 ± 5.77										
Jun 15	3	9.3 ± 4.41						X				
Jun 16	12	10.4 ± 2.90	X			X		X				
Jun 17	11	6.5 ± 2.02	X			X		X	X			

An X indicates that the numbers flushed were not statistically similar on those two dates (i.e.,  $P \leq 0.20$ ), Kruskal-Wallis test.

at least one cornfield was not significant (Table 4). The proportion of moths at sites with no corn to moths at sites with at least one cornfield the previous year did not change over time (Fig. 1B).

The number of European corn borer moths in the grass adjacent to at least one field with minimum-tilled corn stubble ( $30.7 \pm 6.59$ ;  $n = 25$ ) did not differ significantly from the number of moths at sites with no minimum-tilled stubble present ( $43.9 \pm 6.50$ ;  $n = 43$ ) according to a Wilcoxon rank sum test (Daniel 1990) for the period 26 May to 14 June 2004, when global moth populations were similar (normal approximation = 1.833;  $P = 0.067$ ). Likewise, Wilcoxon matched-pairs signed-ranks comparisons of sites with versus sites without minimum-tilled corn stubble across all dates indicated no significant difference ( $n = 9$ ; normal approximation = 0.592;  $P = 0.55$ ). Nevertheless, there is other evidence that the presence of minimum-tilled corn stubble from the previous year had a weak influence on moth distribution. At sites where no current corn was planted, but where at least one of the adjacent fields had minimum-tillage corn stubble, the number of moths in the grass declined over time during the dates when global populations were similar (Fig. 2A). There was no such relationship with time at sites where there was conventional-tilled corn stubble on either or both sides but no minimum-tilled stubble and no current corn (Fig. 2B).

Corn Phenology

The number of leaves per plant in the phenologically most advanced cornfield per site was statistically similar on all four sampling dates in 2003 (Table 1). Regression of moths flushed in 100 m of grass in a borrow ditch on the number of leaves in the most advanced adjacent cornfield was not significant (Fig. 3). However, an apparent outlier was identified (Fig. 3;  $t = 7.368$ ;  $n = 25$ ; corrected  $P = 0.000005$ ). When excluded from the analysis, the regression was significant, but the amount of variation in moth numbers explained by corn phenology was low ( $r^2 = 0.16$ ).

In 2004, the number of leaves per plant was statistically similar (i.e.,  $P > 0.20$ ) from 28 May to 10 June (Table 5). Although the number of leaves on 15 June also was similar to the earlier dates, the global number of moths on that date was not statistically similar with that of 9 June (Table 2), so only the data from 28 May to 10 June were included in the regression analyses. Extended leaf heights showed almost the same pattern of statistical similarity across dates (Table 5). The number of moths flushed in 200 m of grass in the borrow ditches increased significantly with the number of leaves (Fig. 4) or extended leaf height (data not shown) in the most advanced adjacent cornfield. Again, an apparent outlier was identified in each regression (Fig. 4) (number of leaves:  $t = 6.207$ ,  $n = 37$ , corrected  $P = 0.000015$ ; extended leaf height:  $t =$

Table 3. Mean ± SE no. of European corn borer moths of the first flight flushed from grass in borrow ditches adjacent to zero, one, or two fields planted to corn, either in the year of sampling or in the previous year

Adjacent fields with corn	2003		2004			
	Current crop		Current crop		Previous crop	
	No. of sites	Moths flushed <sup>a</sup>	No. of sites	Moths flushed <sup>b</sup>	No. of sites	Moths flushed <sup>b</sup>
0	9	6.6 ± 2.78a	23	21.2 ± 4.44a	18	45.9 ± 13.17a
1	13	22.4 ± 6.58ab	22	40.9 ± 6.74b	18	47.6 ± 8.94a
2	13	56.1 ± 15.57b	23	55.1 ± 10.95b	32	30.3 ± 4.81a

Means within a column followed by the same letter are not significantly different ( $\alpha = 0.05$ ), Kruskal-Wallis test.

<sup>a</sup> Per 100 m of grass from one borrow ditch only.

<sup>b</sup> Per 200 m of grass, totaled from 100 m each in both borrow ditches.

Table 4. Wilcoxon matched-pairs signed-ranks comparisons of mean moths flushed by sampling date in 2003 and 2004 for sites with fields on zero, one, or two sides of the road planted to corn

Sides of road with corn	Current year's crops (2003 and 2004 combined)					Previous year's crops (2004)				
	No. of dates	Mean difference ± SE	Σ negative ranks	Σ positive ranks	One-tailed <i>P</i> <sup>a</sup>	No. of dates	Mean difference ± SE	Σ negative ranks	Σ positive ranks	One-tailed <i>P</i> <sup>a</sup>
0-1	15	-16.2 ± 5.03	-108	12	0.0021	11	-11.5 ± 5.86	-46	9	0.032
0-2	14	-32.2 ± 6.75	-104	1	0.0001	11	9.94 ± 7.44	-16	50	0.926
0-(1 or 2)	15	-27.0 ± 4.55	-120	0	<0.0001	11	3.08 ± 7.53	-31	35	0.496
1-2	14	-16.8 ± 9.17	-78	27	0.0623	11	16.0 ± 8.40	-13	42	0.920

<sup>a</sup> One-tailed probability that site with less cornfields did not have fewer moths than site with more cornfields.

6.059, *n* = 37, corrected *P* = 0.000022). Exclusion of the outlier rendered the extended leaf height regression nonsignificant (*F* = 2.42; *df* = 1,36; *P* = 0.129), but the relationship remained significant for number of leaves, albeit with a reduced coefficient of determination (Fig. 4). Even with inclusion of the outliers, the amount of variation in moth numbers explained by corn phenology was low (*r*<sup>2</sup> = 0.16–0.19).

Discussion

Distribution of European corn borer moths among grassy ditches across the landscape in central Iowa during the first flights of 2003 and 2004 was strongly influenced by cropping patterns. Although at least a few moths were typically found in grass in the absence of an adjacent cornfield, considerably more

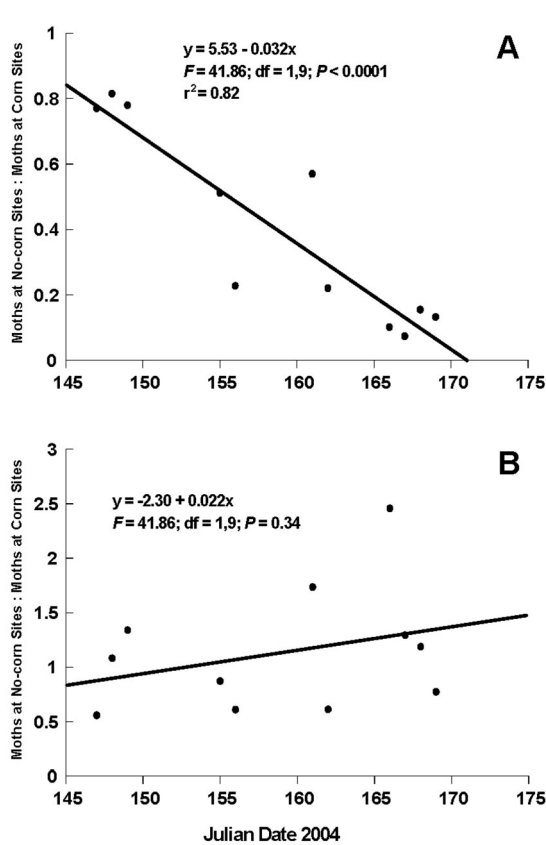


Fig. 1. Linear regression of the ratio of the number of European corn borer moths flushed from borrow ditches without corn on either side to those with corn on at least one side versus time (sample date, 2004). Based on cropping pattern of corn of (A) the current year and (B) the previous year.

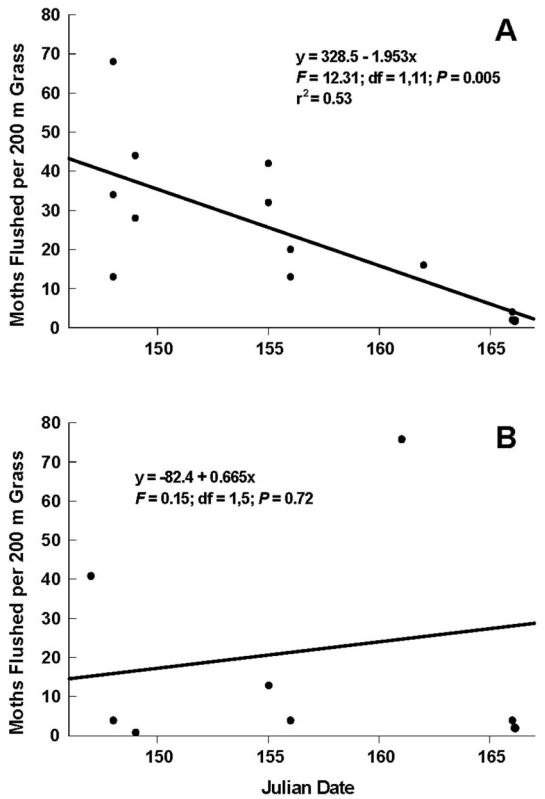


Fig. 2. Linear regression of the number of European corn borer moths flushed with a 1.5-m bar from 100 m of grass in both borrow ditches per site, combined (200 m total), versus time (sample date, 2004). Sites where no current corn was planted, and (A) where at least one of the adjacent fields had minimum-tilled corn stubble or (B) where there was conventional-tilled corn stubble on either or both sides, but no minimum-tilled corn stubble.



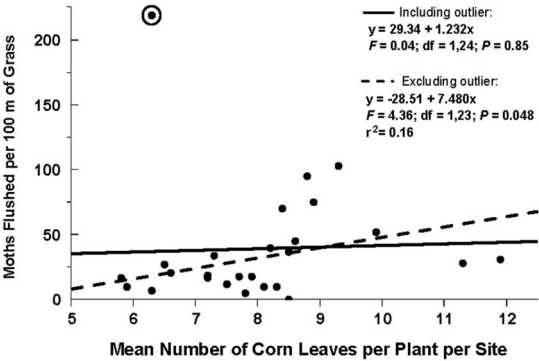


Fig. 3. Linear regression of the number of European corn borer moths flushed with a 1.5-m bar from 100 m of grass in one borrow ditch per site (2003) versus the mean number of leaves on corn plants in the phenologically most advanced adjacent corn field. Probable statistical outlier circled.

moths were found in ditches located in proximity to at least one cornfield. The observed differential increased over the duration of the flight, indicating that moths progressively redistributed themselves across the landscape relative to the presence or absence of nearby corn. This outcome was somewhat anticipated given that corn clearly is the preferred host of the European corn borer in most of the Corn Belt (Kennedy and Margolies 1985, Kennedy and Storer 2000, Losey et al. 2001) and that there is a direct correspondence between the number of moths in aggregation sites and number of egg masses deposited in the field, at least during the second flight (Showers et al. 1980, Derrick and Showers 1990). Although moth aggregations have been found in grass at least 100 m from the nearest corn (Showers et al. 1976), our results indicate that moth distribution among grassy sites in the landscape is not random and that moths prefer to aggregate near corn, provided acceptable grass is present.

Table 5. Mean  $\pm$  SE extended leaf heights and leaves per plant of corn adjacent to sites where European corn borer moths were flushed from grassy ditches, first flight 2004

Date	No. sites	Extended leaf height (cm)	Leaves per plant
May 26	4	27.2 $\pm$ 3.15a	4.5 $\pm$ 0.32a
May 27	7	30.5 $\pm$ 2.76a	5.0 $\pm$ 0.26a
May 28	6	29.3 $\pm$ 5.63a	3.9 $\pm$ 0.60a
Jun 3	6	40.9 $\pm$ 2.93ab	5.3 $\pm$ 0.12ab
Jun 4	8	43.2 $\pm$ 2.10ab	5.4 $\pm$ 0.22ab
Jun 9	3	56.0 $\pm$ 8.31abc	7.2 $\pm$ 0.25abc
Jun 10	4	72.3 $\pm$ 5.90abc	7.6 $\pm$ 0.26abc
Jun 14	6	97.3 $\pm$ 8.80bc	8.9 $\pm$ 0.33bc
Jun 15	2	54.7 $\pm$ 3.70ac	7.0 $\pm$ 0.20abc
Jun 16	7	112.1 $\pm$ 6.29c	9.5 $\pm$ 0.23c
Jun 17	7	113.5 $\pm$ 3.59c	9.6 $\pm$ 0.34c

When two cornfields were present at a site (i.e., corn on both sides of the road), only the one with the tallest corn (or max leaves) was used in comparisons across dates.

Means followed by the same letter are statistically similar ( $P > 0.20$ ), Kruskal-Wallis test.

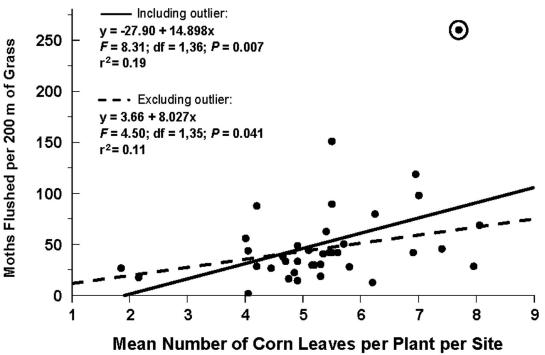


Fig. 4. Linear regression of the number of European corn borer moths flushed with a 1.5-m bar from 100 m of grass in one borrow ditch per site (2004) versus the mean number of leaves on corn plants in the phenologically most advanced adjacent corn field. Probable statistical outlier circled.

It is sometimes assumed that continuous cornfields harboring overwintering populations of this insect, as well as neighboring fields, may be at greater risk of first generation infestation than first-year cornfields after soybeans, from which moths would not be emerging (e.g., Baute 2003). Such risk would be even greater for minimum-tilled corn stubble, because overwintering mortality is less than in conventionally tilled fields (Umeozor et al. 1985). For this assumption to be valid requires that female moths of the overwintered generation aggregate in adjacent grassy areas soon after emergence and show fidelity to that site as a staging area for oviposition in adjacent fields over a substantial portion of their reproductive lifetime. The data reported here do not support this scenario. For the most part, spatial distribution of first-flight moths in the landscape was not related to the presence of corn stubble, as would be expected if newly emerged moths aggregated close to their natal field and remained there over time. Furthermore, the number of moths in ditches adjacent to minimum-tilled corn stubble declined over time in the absence of a new crop of corn. This pattern suggests that at least some moths emerging from a field may aggregate in the adjacent grass but that they redistribute themselves in the landscape over time.

This finding is consistent with results reported by Showers et al. (2001) that a small proportion of laboratory-reared moths was found in nearby aggregation sites the morning after emergence from pupal rings but that they dispersed out of the area the following night. In another study (Showers et al. 1976), moths that were at least 1 d old were released early in the morning into plots of Sudan grass, where they stayed all day. However, they dispersed the following night, so that  $<10\%$  were in the same grass the next morning. Both of these studies indicate a lack of fidelity to initial aggregation sites, at least in the case of young laboratory-reared moths. The pattern observed in this study of progressive redistribution of moths away from their presumed natal field was detectable only in the

absence of corn, indicating that any effects of the previous year's cropping patterns on adult distribution were short lived and swamped by the influence of the current year's crops.

An estimated 37% of corn acreage in Iowa in 2003 was planted to transgenic *Bt* varieties active against the European corn borer (National Agricultural Statistics Service 2004). Stubble from *Bt* corn planted in 2003 would not be a source of moths in 2004, so it is possible that the observed numbers of moths near corn stubble were lower than would be expected if all corn from the previous year was non-*Bt*. I did not attempt to determine the *Bt*/non-*Bt* history of the fields adjacent to the grass where the moths were sampled. Nevertheless, the evidence for moth redistribution over time was detected despite any confounding effects of *Bt* corn stubble on initial distribution, and the important conclusion remains that, if moths temporarily colonize the grass near their natal field, they do not stay there long.

During the first flight, European corn borers prefer to oviposit on the most phenologically advanced corn plants in an area, putting early planted cornfields at greater risk of first-generation infestation than later planted cornfields (Huber et al. 1928, Brindley and Dicke 1963, Anderson et al. 1984, Mason et al. 1996, Spangler and Calvin 2000, Pilcher and Rice 2001). Thus, I tested the hypothesis that the number of adults in grassy areas would be related to corn phenology. Indeed, grassy areas adjacent to fields with more advanced corn, as measured by number of leaves and extended leaf height, tended to harbor more moths than sites adjacent to less advanced corn. However, the effect was weak, with only 10–20% of the variation in moth numbers among sites explained by corn phenology.

Overall, the results indicate that European corn borer adult distribution among suitable grassy aggregation areas in roadside ditches is not random during the first flight. Although this distribution is affected by relative corn phenology and possibly by nearness of the natal field, these effects are weak. Instead, spatial distribution is overwhelmingly influenced simply by the presence or absence of corn at a site. Appropriate grass habitats must be present as well but are exceedingly common in the borrow ditches of bordering roads, fence lines, and in waterways traversing fields, throughout much of the rain-fed U.S. Corn Belt, and it seems unlikely that suitable aggregation sites per se are an important limiting factor in first-flight moth distribution at the landscape scale.

Understanding the factors that influence European corn borer moth distribution and the dispersal behavior that drives that distribution will be critical to developing effective novel pest management tactics exploiting this insect's aggregation behavior (Hellmich et al. 1998, Anderson et al. 2003). Such understanding also will be essential to better parameterization of dispersal components in insect resistance management models (Hellmich et al. 1998, Hunt et al. 2001) and to developing effective mitigation strategies, should resistance to insecticides, including to trans-

genic *Bt* toxins, be detected in local populations (Andow and Ives 2002).

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